[REPORT DOCU]MENTATION PAGE

Form Approved OMB No. 0704-0188

[Public reporting burden for this collection of information is] estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, [gatherin]g and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this [collection of information, including suggestions for reducin]g this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson [Davis Highway, ...] to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

[2.] REPORT DATE	November 30, 1992
3. REPORT TYPE AND DATES COVERED	FINAL 11/01/88 - 7/31/92
4. TITLE AND SUBTITLE	Experimental Studies of Fundamental Problems in Quantum Optics
5. FUNDING NUMBERS	DAAL02-89-K-0004
6. AUTHOR(S)	Thomas W. Mossberg Michael G. Raymer
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	University of Oregon Eugene OR 97403
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	U. S. Army Research Office P. O. Box 12211 Research Triangle Park, NC 27709-2211
10. SPONSORING/MONITORING AGENCY REPORT NUMBER	ARO 25546.16-PH
11. SUPPLEMENTARY NOTES	The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.
12a. DISTRIBUTION/AVAILABILITY STATEMENT	Approved for public release; distribution unlimited.
12b. DISTRIBUTION CODE	

13. ABSTRACT *(Maximum 200 words)*

Extensive experimental and theoretical results obtained in the two research areas supported by this grant are summarized. These diverse areas include the statistical properties of light produced via stimulated Raman scattering and the operational and technical properties of the time-domain frequency-selective approach to optical data storage.

14. SUBJECT TERMS	Stimulated Raman Scattering Optical Information Storage
15. NUMBER OF PAGES	8
16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT	UNCLASSIFIED
18. SECURITY CLASSIFICATION OF THIS PAGE	UNCLASSIFIED
19. SECURITY CLASSIFICATION OF ABSTRACT	UNCLASSIFIED
20. LIMITATION OF ABSTRACT	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89) Prescribed by ANSI Std 239-18 298-102

STATEMENT OF PROBLEM STUDIED

The work of M.G. Raymer's group during this period has been directed toward--

- Spatial and temporal properties of light generated by amplification of quantum noise in gain-guiding amplifiers.
- Optical phase memory in coherently excited optical amplifiers.

We have used stimulated Raman scattering as a prototypical and important instance of gain-guided optical amplifier. Several successful experiments have been accomplished, along with the necessary theoretical modelling. Optical parametric amplifiers have also been studied theoretically.

T.W. Mossberg's group has concentrated on the elucidation of new approaches to time-domain frequency-selective optical data storage and material problems associated therewith.

SUMMARY OF RESULTS

1. **Spatial Interference of Light from Independent SRS Sources** -- We have demonstrated that the creation of spatial fringes occurs when two beams of Raman-generated light are superposed. Because the beams are generated from independent groups of molecules, they are statistically independent, and have random, uncorrelated phases and amplitudes. Thus the locations and depth of modulation of the fringes vary on each shot of laser. We have verified that the statistics of the light is identical to thermal radiation with an effective temperature as high as 10^{12} Kelvin.

2. **Excess Spontaneous Noise in Gain-Guided Amplifiers** -- Much has been made recently about an unusual and subtle effect that occurs in gain-guided semiconductor lasers. The modes of the structure are non-orthogonal and this leads to correlations between mode amplitudes, and so-called excess noise. We have discovered that this effect is also present in gain-guided amplifiers without resonators, such as Raman or X-ray amplifiers. By measuring the shot-to-shot jitter of the direction of propagation of the generated beam, we have been able to show that the non-orthogonality of the gain-guided modes plays an important role in the spatial structure of the light.

We carried out experiments and developed theoretical models to understand the quantum mechanical origin of the directional instability of the Stokes beam generated by SRS in a molecular gas such as hydrogen. For interaction Fresnel numbers greater than about five, we demonstrated for the first time that the Stokes beam direction fluctuates on the order of the diffraction-limited divergence angle. We measured the beam-angle standard deviation versus Fresnel number by employing a new interferometric technique in which two Stokes beams generated in different media are made to interfere spatially. The fringe spacing is a measure of the relative pointing angle.

The theory that we have developed to successfully fit the measurements is based on a transverse mode expansion of the Stokes field that naturally accounts for the gain guiding of the field by the laser-pumped Raman medium. So-called excess spontaneous-emission noise is incorporated in this model and is important for correctly describing the field statistics.

3. **Near-Quantum Limited Phase Memory in a Raman Amplifier** -- We developed a new technique for measuring very small amounts of vibrational coherence in a high-density gas of molecules. By spatially interfering two Stokes pulses, produced in sequence in the same sample of molecules, we were able to detect on the order of 20 coherently vibrating molecules, in the presence of about 10^{16} incoherently vibrating molecules. This approaches the quantum limit on the amount of detectable vibration in a gas.

4. **Squeezing in Wide-band Parametric Amplification** -- We have developed a theoretical model for predicting the properties of light generated by wide-band, travelling-wave parametric amplification in nonlinear optical crystals. In particular, we analyzed the effects of group-velocity dispersion on the amount of phase-quadrature squeezing (reduction of quantum noise) that can be achieved in such amplifiers.

5. **Excitation-induced Frequency Shifts in Inhomogeneously Broadened Absorbers**-- We have discovered a new property of solid-state optical absorbers. When such materials are exposed to resonant optical radiation and thereby promoted to excited atomic states, their optical transition frequencies are shifted. This effect must be taken into account in many experiments designed to study optical dephasing in solids. The effect must also be considered in the design of time-domain optical memories.

6. **Phase-noise and Time-domain Frequency-selective Optical Data Storage** -- It was demonstrated that new classes of optical pulses are effective in the storage of time-domain optical data. These pulses are imbued with pseudo-random phase noise. It turns out that information stored with such pulses cannot be recalled without knowledge of the pseudo-random phase noise used in the storage process. As a result, a new means of secure data storage is provided.

7. **Swept-Carrier Time Domain Optical Memory** -- An entirely new scheme of time-domain optical memory was proposed. In this scheme, long cotemporal, frequency-swept excitation pulses are employed. The new approach facilitates the use of full material bandwidth without requiring the use of extreme data modulation rates. Many more materials should be useable with the now swept-carrier approach.

PUBLICATIONS

1. "Beam-pointing fluctuations in gain-guided amplifiers," Phys. Rev. Lett. **66**, 2605 (1991), S. J. Kuo, D. T Smithey and M. G. Raymer.

2. "Near-quantum limited phase memory in a Raman amplifier," Phys. Rev. Lett. **67**, 2446 (1991), D. T Smithey, M. Belsley, K. Wedding and M. G. Raymer.

3. "Spatial interference of macroscopic light fields from independent Raman sources," S. J. Kuo, D. T. Smithey and M. G. Raymer, Phys. Rev. A (Rapid Commun.) **43**, 4083 (1991).

4. "Temporal quantum fluctuations in stimulated Raman scattering: coherent modes description," M. G. Raymer, Z. W. Li, and I. A. Walmsley, Phys. Rev. Lett. **63**, 1586 (1989).

5. "Quantum theory of propagation of non-classical radiation in a near-resonant medium," P. D. Drummond and M. G. Raymer, Phys. Rev. A **44**, 2072 (1991).

6. "Observation of extreme sensitivity to induced molecular coherence in stimulated Raman scattering," M. Belsley, D. T. Smithey, and M. G. Raymer, (to be submitted to Phys. Rev. A, fall 1992).

7. "Quantum statistics in nonlinear optics," (book chapter) J. Mostowski and M. G. Raymer, in Contemporary Nonlinear Optics, eds. R. W. Boyd and G. P. Agrawal (79 pages, Academic, Boston, 1992).

8. "The quantum coherence properties of stimulated Raman scattering," M.G. Raymer and I.A. Walmsley, in "Progress in Optics" (E. Wolf, ed.), Vol. XXVIII, p. 181-270 (North Holland Elsevier, Amsterdam, 1990).

9. "Limits to wide-band, pulsed squeezing in a traveling-wave, parametric amplifier

with group-velocity dispersion," M. G. Raymer, P. D. Drummond and S. J. Carter, Optics Letters 16, 1189 (1991).

10. "Influence of collisional dephasing processes on superfluorescence," J. J. Maki, M. S. Malcuit, M. G. Raymer and R. W. Boyd, Phys. Rev. A 40, 5135 (1989).

11. "The quantum spatial coherence properties of stimulated Raman scattering," Shihjong Kuo (PhD thesis, 1991, Univ. of Rochester).

12. "Optical dephasing, hyperfine structure, and hyperfine relaxation associated with the 508.8nm $^7F_0$-$^5D_0$transition of europium in $Eu^{3+}:Y_2O_3$," W. R. Babbitt, A. Lezama, and T. W. Mossberg, Phys. Rev. B39, 1987 (1989).

13. "Excess dephasing in photon-echo experiments arising from excitation-induced electronic level shifts," J. Huang, J. M. Zhang, A. Lezama, and T. W. Mossberg, Phys Rev. Lett. 63, 78 (1989).

14. "On the shifting of optical transition frequencies in rare-earth-doped insulators by resonant optical excitation," J. Huang, J. M. Zhang, A. Lezama, and T. W. Mossberg, J. Luminescence 45, 392 (1990).

15. "Excitation-induced frequency shifts and frequency-dependent dephasing in $Eu^{3+}:Y_2O_3$," J. Hunag, J. M. Zhang, and T. W. Mossberg, Opt. Commun. 75, 29 (1990).

16. "On the use of phase-noisy laser fields in the storage of optical pulseshapes in inhomogeneously broadened absorbers," J. M. Zhang, D. J. Gauthier, J. Huang, and T. W. Mossberg, Opt. Let. 16, 103 (1991).

PERSONNEL

1. Michael G. Raymer -- PI, Professor of Physics
2. Shih-Jong Kuo, obtained PhD degree in April, 1991.
3. Daniel T. Smithey, PhD student, planned graduation date--7/92
4. Shuangbo Yang, PhD student
5. Shunichi Nishimura, MS student--planned graduate date--12/92
6. Dr. Jin Huang
7. Jiamin Zhang
8. Dr. Daniel Gauthier
9. Prof. Thomas W. Mossberg

INVENTIONS

Swept-carrier time-domain optical memory, T. W. Mossberg (patent applied for).